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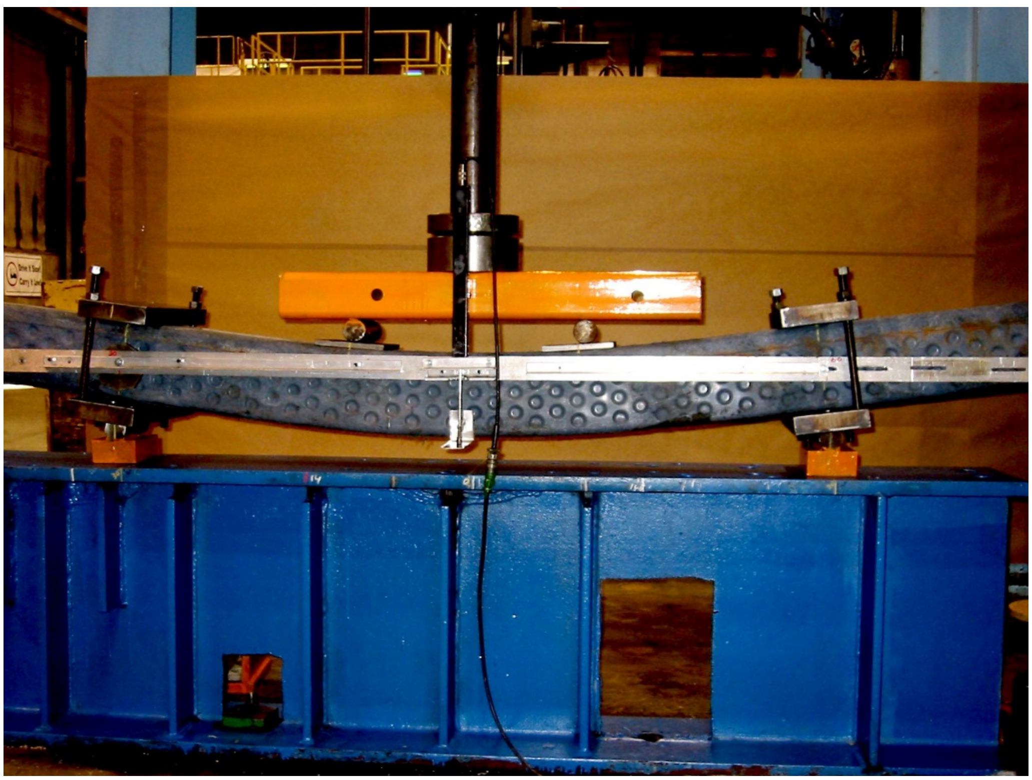
Investigation of Bending Test Procedures for Engineered Polymer Composite Railroad Ties

Claire G. Ball

December 2016



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December 2016

Investigation of Bending Test Procedures for Engineered Polymer Composite Railroad Ties

Claire G. Ball

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Final report

Prepared for Federal Railroad Administration (FRA)
Office of Research and Development
Washington, DC 20590

Under Interagency Agreement No. DTFR53-13-X-00103/0002, "Track Safety Issues Regarding the Use of Plastic Tie Technologies"

Monitored by Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
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Abstract

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) has been conducting investigations to help develop and evaluate engineered polymer composite railroad ties since 1993. Recent efforts, through funding and support from the Federal Railroad Administration, center on track-safety issues relative to the use of these new products in mainline heavy axle load track. Performance criteria have been developed and published in Chapter 30 of the American Railway Engineering and Maintenance-of-Way Association's (AREMA) *Manual for Railway Engineering*. One item not completely resolved in this engineering guidance is the testing procedure for measuring the bending strength and modulus of elasticity (i.e., stiffness) of the composite ties. The objective of this investigation was to compare variations in bending-strength test methods currently being used to measure strength and modulus values for engineered polymer composite railroad ties.

Foreword

Construction Technology Laboratories, Inc. (now CTL Group), Skokie, IL, was contracted by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) to conduct and compare variations of bending-test methods as might be appropriate to measure strength and modulus values for engineered polymer composite railroad ties. ERDC-CERL has been conducting investigations to help develop and evaluate engineered polymer composite railroad ties since 1993. Through funding support from the Federal Railroad Administration, U.S. Department of Transportation, ERDC-CERL studies focused on track-safety issues relative to the use of these new products in mainline, heavy-axle-load track.

Performance criteria for these ties were developed and published in Chapter 30 of the American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering* (2003). One item not fully resolved in that guidance is the most appropriate test method procedure to measure bending strength and modulus (stiffness) of polymer composite ties. CTL performed bending tests on standard 7 x 9 in. polymer composite ties using a four-point bending test (ASTM D 6109, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber and Related Products*) and a standard three-point bending test as typically used for wood ties. A 60 in. lower span (replicating standard rail spacing) was used for both the four- and three-point methods. Crosshead speeds were varied from 0.1, 1, 5, and 10 in. per minute. The primary goal of this effort was to provide recommendations for a standard bending-test procedure for polymer composite ties that can be included in a future update of Chapter 30, "Ties," Part 5, Engineered Composite Ties, of the AREMA manual. Their report (reproduced in its entirety here) outlines the testing procedures conduced, provides a discussion of the results, and makes recommendations for changes to the existing standard practice provided in AREMA Chapter 30. Changes were incorporated in the 2009 edition of AREMA Chapter 30.

Richard G. Lampo
Materials Engineer and Project Manager
ERDC-CERL

Preface

This study was conducted for the Federal Railroad Administration (FRA), Office of Research and Development, through Interagency Agreement No. DTFR53-13-X-00103/0002, "Track Safety Issues Regarding the Use of Plastic Tie Technologies." The FRA technical monitor was Mahmood Fateh.

The study was performed for the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) by CTL Group, Skokie, IL, under Contract W9132T-05-P-0091, dated 12 June 2005. Work was monitored by the Materials and Structures Branch of the Facilities Division (CEERD-CFM), ERDC-CERL. The project manager and Contracting Officer's Technical Representative was Richard G. Lampo, CEERD-CFM. At the time of publication, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF and Kurt Kinnevan, CEERD-CZT was the Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

The Commander of ERDC was COL Bryan S. Green and the Director was Dr. Jeffery P. Holland.

US Army Engineering Research and Development Center – Construction Engineering Research Laboratory

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INVESTIGATION OF BENDING TEST PROCEDURES FOR ENGINEERED POLYMER COMPOSITE RAILROAD TIES

Date:
September 21, 2006

Submitted by:
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INVESTIGATION OF BENDING TEST PROCEDURES FOR ENGINEERED POLYMER COMPOSITE RAILROAD TIES

by

Claire G. Ball *

SUMMARY HIGHLIGHTS

CTLGroup (CTL), formerly known as Construction Technology Laboratories, Inc., was retained to conduct flexural bending moment tests to investigate the influence testing methods have on the measured strength properties of engineered polymer composite railroad ties.

Polywood composite ties having nominal dimensions of 7 in. x 9 in. x 108 in. long were supplied for the testing program by the Chicago Transit Authority. Two currently used test methods and four loading rates were evaluated in this test program. The bending moment tests were conducted in accordance with American Society for Testing and Materials (ASTM) Flexural Strength, ASTM D6109-03, Method A, Flat or "Plank" Testing Procedures and the American Railway Engineering and Maintenance-of-Way Association (AREMA), Volume 1, Chapter 30 Testing Procedures for Railroad Ties. The loading support span was maintained at 60 in. for all tests. Four loading rates, 0.1, 1, 5, and 10 in./min were evaluated for the ASTM method and two loading rates, 1 and 5 in./min, were evaluated for AREMA test method.

Results of the twenty-six (26) flexural bending moment tests are summarized in Table 1. Stress-deflection loading rate trend lines are presented in Fig. 1. The average modulus of rupture values (MOR) for the ASTM tests at the loading rates of 0.1, 1, 5, and 10 in./min were 2,143, 2,599, 2,831, and 2,212 psi, respectively. The average MOR for the AREMA tests at the loading rates of 1 and 5 in./min were 3,132, and 3,040 psi, respectively. As requested by Mr. Richard Lampo, Construction Engineering Research Laboratory (CERL), the flexural modulus of elasticity (MOE) was calculated as a tangent line from zero to 400 and 600 psi loads and 1% and 3% strain loads. The average MOE calculated values decreased for all test methods as

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TABLE 1 TIE BENDING MOMENT TEST SUMMARY

Test Method	Loading Rate (in./min)	Tie ID	Modulus of Rupture (MOR)		1% Strain	3% Strain
			Stress (psi)	Deflection (in.)		
ASTM	0.1	Average	2,143	4.667	959	1,893
ASTM	1	Average	2,599	4.005	1,235	2,427
ASTM	5	Average	2,831	4.099	1,339	2,671
ASTM	10	Average	2,212	2.158	1,393	-
AREMA	1	Average	3,132	3.445	1,386	2,943
AREMA	5	Average	3,040	2.943	1,416	2,736

Notes: For ASTM Tests – 1% strain = 1.09 in. deflection, 3% strain= 3.28 in. deflection
For AREMA Tests – 1% strain = 0.86 in. deflection, 3% strain = 2.56 in. deflection

Test Method	Loading Rate (in./min)	Tie ID	Modulus of Elasticity (MOE)			
			0 to 400 psi	0 to 600 psi	1% Strain	3% Strain
ASTM	0.1	Average	126,800	113,800	95,900	63,100
ASTM	1	Average	156,900	147,400	123,500	80,900
ASTM	5	Average	171,400	164,500	133,900	89,000
ASTM	10	Average	174,700	165,000	139,300	-
AREMA	1	Average	168,100	162,100	138,600	98,100
AREMA	5	Average	197,900	169,800	141,600	91,200

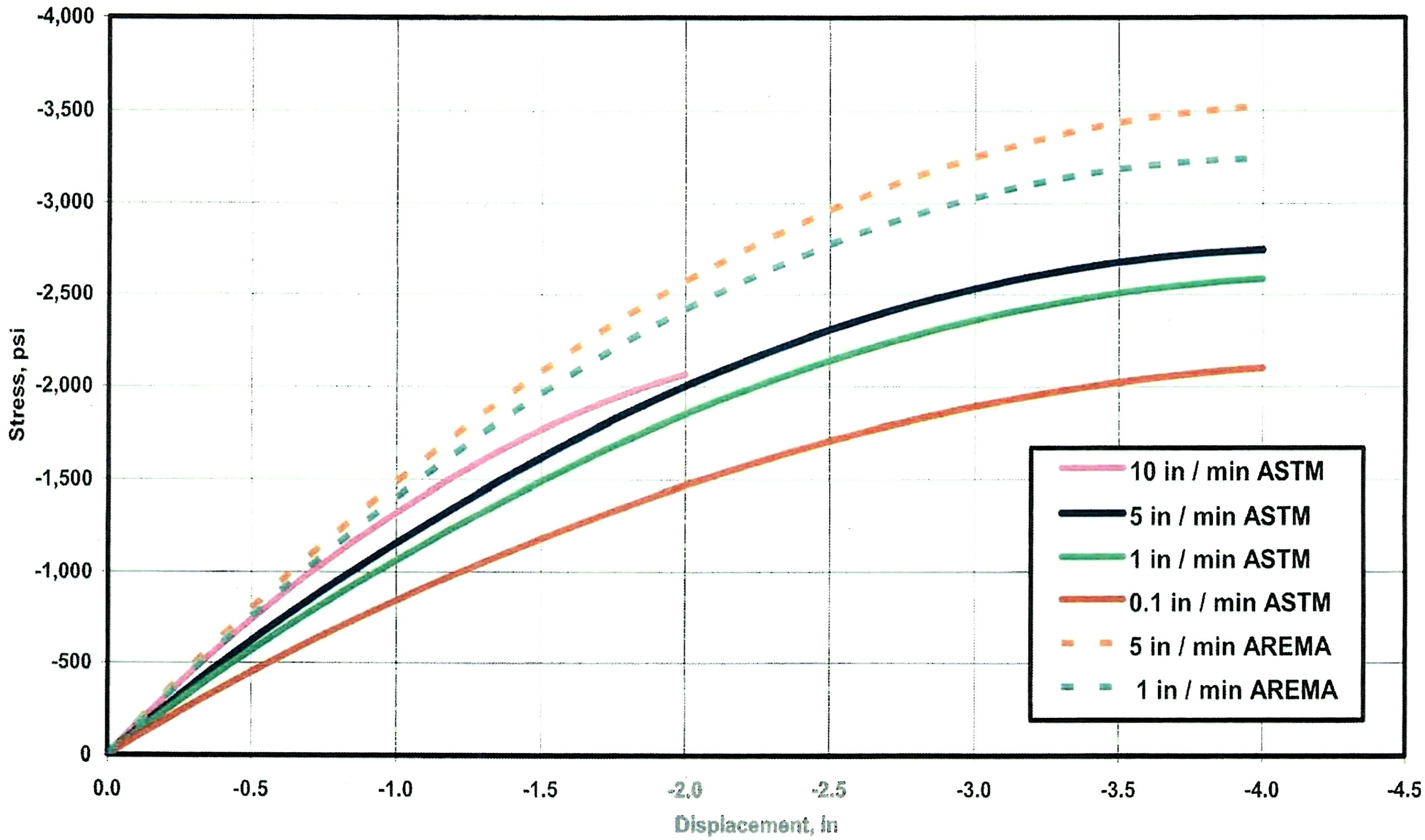

Fig. 1 Composite tie bending tests – stress-deflection trend lines.

the stress range used increased from 0 to 400 psi, 0 to 600 psi,1% strain, and 3% strain. The 0 to 600 psi calculated average MOE for the ASTM tests at 0.1, 1, 5, and 10 in./min were 113,800, 147,400, 164,500, and 165,000 psi, respectively. The 0 to 600 psi calculated average flexural MOE for the AREMA tests at 1 and 5 in./min were 162,100 and 169,800 psi, respectively.

Test results indicate that, for the MOR and MOE strengths obtained for the two testing methods and same two loading rates for each method, the AREMA test method conducted at the higher, 5 in./min, loading rate gave the highest values. The 5 in./min loading rate produced approximately 9% higher flexural stresses than the 1 in./min loading rate for the ASTM testing method. However, the two loading rates investigated did not significantly affect the flexural stresses for the AREMA testing method. At both loading rates, the AREMA test method produced higher stresses (approximately 15% at the 1 in./min load rate and approximately 5% at the 5 in./min load rate). Additionally, the slower ASTM loading rate of 0.1 in./min produced approximately 21% lower MOR and MOE strengths than the 1 in./min load rate and the higher load rate of 10 in./min produced approximately 2 to 4% higher 1 and 3% strain and MOE stresses than the 5 in./min load rate. However, the 10 in./min did produce approximately 22% lower MOR strength and approximately 47% less deflection than the 5 in./min loading rate.

In general, a comparison of the calculated MOE values indicates that they had similar trends to the flexural stresses when compared to the test method and loading rate. As expected, the MOE values decreased as the maximum point on the stress-strain curve (load-deflection curve) used to calculate the MOE increased from 400 psi to 600 psi to 1% strain to 3% strain.

INTRODUCTION

CTLGroup was retained by the US Army Engineering Research and Development Center – Construction Engineering Research Laboratories (ERDC-CERL) to conduct flexural bending moment tests on Polywood engineered polymer composite railroad ties. The purpose of the program was to compare the influence currently used bending moment test methods have on the strength value results being obtained for composite ties.

This report contains a description of the background, test samples, test procedures, and results of the testing program.

BACKGROUND

ERDC-CERL has been conducting investigations to help develop and evaluate engineered polymer composite railroad ties since 1993. Current efforts, through funding support from the Federal Railway Administration, center around track safety issues relative to the use of these new products in mainline heavy axle load track. Performance criteria have been developed and published in Chapter 30 of the American Railroad Engineering and Maintenance-of-Way Association's (AREMA) Manual for Railway Engineering. One item not completely resolved in this engineering guidance is the test method procedure to measure the bending strength and modulus of elasticity (stiffness) of the composite ties. The objective of this investigation is to compare variations in bending strength test methods currently being used to measure strength and modulus values for engineered polymer composite railroad ties.

TEST SAMPLES

Approximately 30 composite ties, with nominal dimensions of 7 in. x 9 in. x 108 in. long, were supplied by the Chicago Transit Authority (CTA) for this test program. The CTA ties were randomly taken from a CTA stock pile. There were no fastener systems or spike holes in any of the test ties.

Tie samples were randomly marked by CTL as ASTM Ties No. 1 through Tie No. 17 and AREMA Ties No. 1 through Tie No. 10. Samples were made by Polywood and an end of each tie was stamped PWI.

TEST PROGRAM

The two test methods commonly used to determine the bending strength of composite ties were evaluated for the influence of loading rate, by controlling the deflection rate at 1 in./min and a faster loading rate at a deflection rate of 5 in./min. Additionally, one test method was also evaluated for a very slow rate of 0.1 in./min and a higher rate of 10 in./min.

One test method was the ASTM D6109-03, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber. Tests were conducted in general accordance with Method A, Flat or "Plank" Testing Procedures. Though the tests were intended for the evaluation of plastic lumber, they have been adapted for the testing of composite ties. Because the ties have a much larger cross-section than flat lumber planks, the tie bottom surface load reaction support span was set at 60 in. for the tie tests. Loading was applied to the top surface

at points located at the third point of the support span, as specified in Fig. 1 of the ASTM Standard and shown in report Fig. 2. Per the standard test method, the test loads were distributed to the tie at the two loading locations and two support locations with 6 in. wide steel plates to avoid excessive indentations and stress concentrations directly under the load and support locations. The support span plates were secured to the tie with top and bottom plates to hold the plates in place when the tie deflection increased to over 2 in. and the supports plate would otherwise tend to slide on the tie. The load was applied with rollers to accommodate slight changes in the load contact locations when the tie deflection increased during testing.

The second test method was the AREMA tie center bending procedures being developed by Tie Committee 30 for the testing of composite ties. As shown in Fig. 3, the tie is supported at a 60 in. span on 1 in. thick by 5-1/2 in. wide rubber pads supporting the full width of the tie. The rubber pad hardness was approximately 50 Shore A. The load was applied to the center of the tie with the same size rubber pad. All loads were applied to the rubber pads with rigid steel plates.

TEST PROCEDURES

All testing was conducted in laboratory ambient conditions (70°F - 75°F) after ties had normalized to the ambient conditions.

The testing load arrangements are shown in Figs. 2 and 3.

Loading was applied by a 50 kip capacity servo hydraulic closed-loop actuator operated in displacement control. Per the testing plan, the four deflection loading rates were 0.1, 1, 5, and 10 in./min. Tie deflection was recorded for each test. The tie load and deflection was monitored with the deflection frame shown in Figs. 2 and 3. The deflection frame was attached to the tie directly over the tie supports at 30 in. each side of the loading center on the longitudinal centerline of the tie. The tie center deflections were referenced to the centerline directly over the support locations to eliminate any support or loading movements from affecting the tie deflection readings. Deflection measures were monitored with a 6 in. stroke electronic displacement transducer attached to the deflection frame and another bracket attached to the center of the tie. Load versus tie mid-span vertical deflection was recorded by a digital data acquisition system and imported to Excel for processing the data.

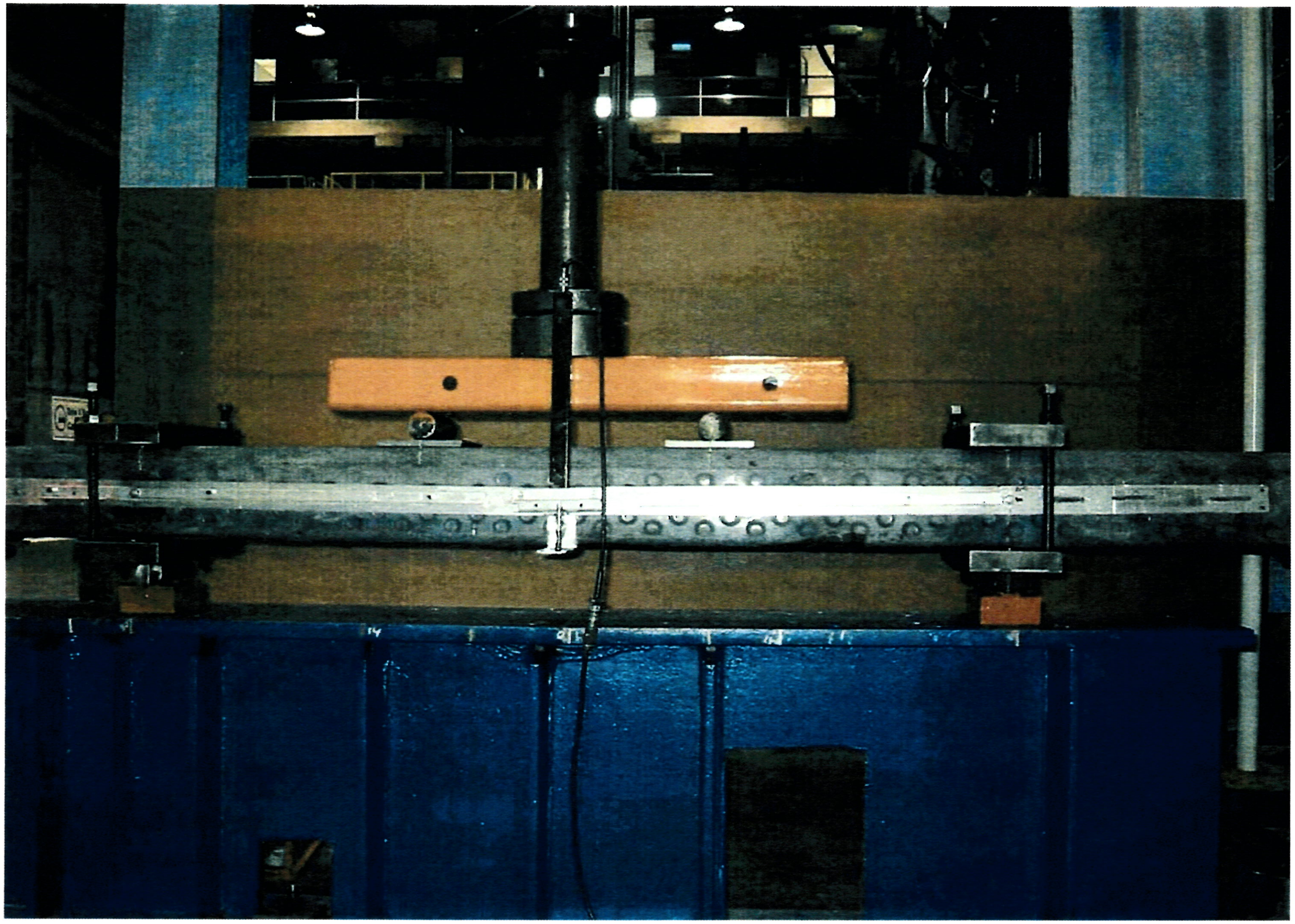

Fig. 2 ASTM test setup.

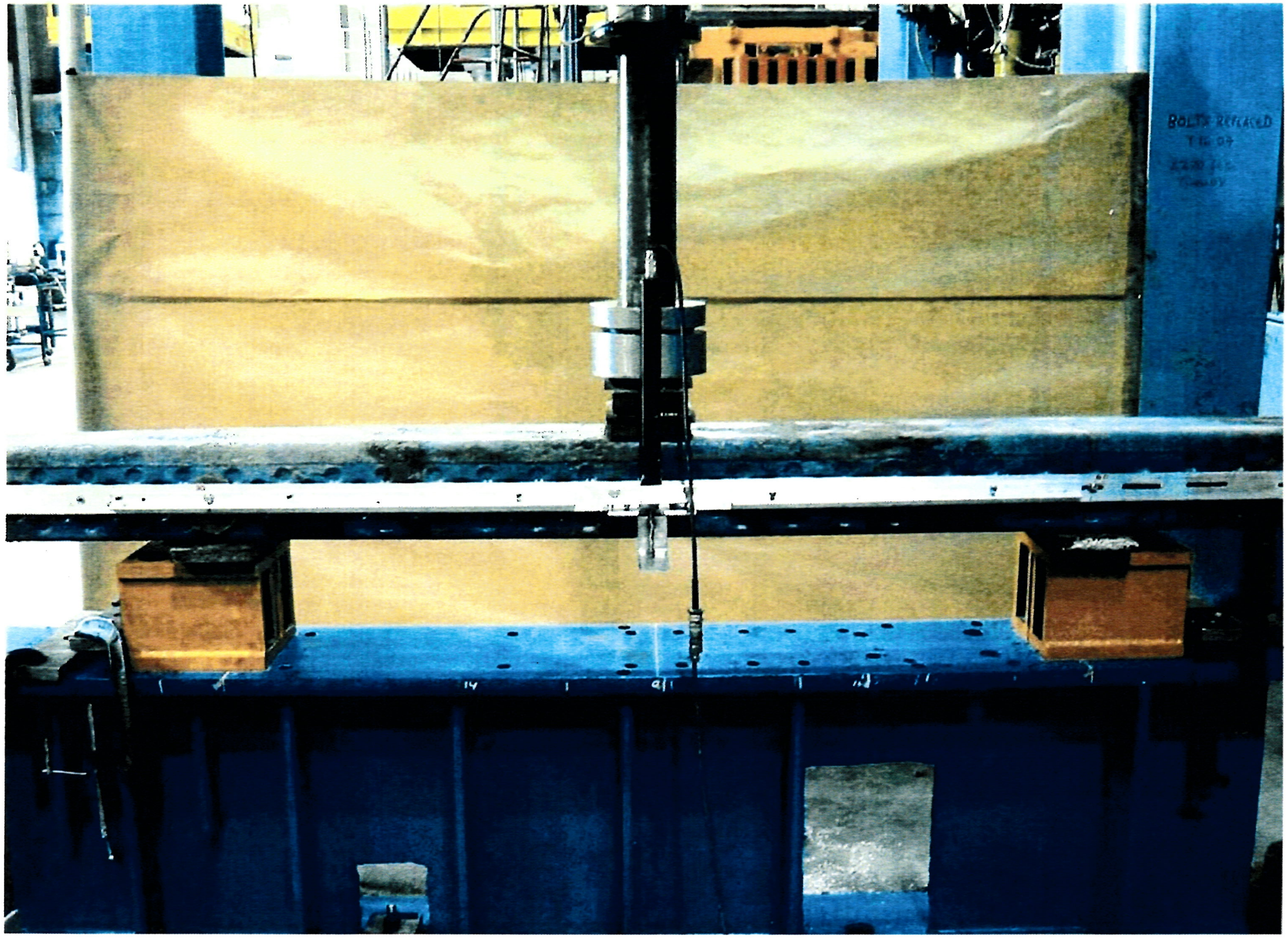

Fig. 3 AREMA test setup.

Flexural modulus of rupture (MOR) strength was calculated at failure load. Tie flexural stresses were also calculated at 1% and 3% tie strain values. The flexural modulus of elasticity (MOE) was calculated from the load-deflection data in the Excel files obtained during each test for 400 psi bending stress, 600 psi bending stress, 1% strain, and 3% strain test data. Equations used for the stress and MOE calculations are presented in Appendix A.

TEST RESULTS

Results of the flexural bending moment tests are summarized in Table 1. The affect of the loading rate on ASTM and AREMA bending test stress-deflection trend plots is shown in Fig. 1.

The average flexural strengths of the ties tested in accordance with the ASTM procedures at the 0.1, 1, 5, and 10 in./min, deflection controlled, loading rates were 2,143, 2,599, 2,831, and 2,212 psi, respectively. The average flexural strengths of the ties tested in accordance with the AREMA procedures at 1 and 5 in./min loading rates were 3,132 and 3,040 psi, respectively. The average tie deflections at MOR for the ASTM tie tests were 4.005 to 4.667 in. at the 0.1, 1, and 5 in./min loading rates and only 2.158 in. for the ties tested at 10 in./min. The average tie deflections at MOR for the AREMA tie tests were 3.194 in. A photograph of an ASTM tested tie just prior to MOR is presented in Fig. 4.

The stress versus deflection curves for the sixteen tie tests conducted in accordance with ASTM procedures are presented in Fig. 5. The stress versus deflection curves for the ten tie tests conducted in accordance with AREMA procedures is presented in Fig. 6.

Tie bending moment test stresses for each tie test are presented in Table 2.

Per the test procedures being investigated, MOE values were calculated for four stress ranges - 0 to 400 psi, 0 to 600 psi, 1% strain and 3% strain. Tie bending moment test MOE values of each tie test are presented in Table 3. As expected, the MOE values decreased as the stress range used for the calculation increased from 400 psi to 3% strain.

CONCLUSIONS

Based on the limited 26 tie tests conducted to compare the ASTM and AREMA test methods and four deflection controlled loading rates, the following trends were observed:

- AREMA test method produces approximately 5 to 15% higher bending stresses than the ASTM test method.

- Test results obtained for the two deflection controlled 1 and 5 in./min loading rates evaluated for both tests methods indicate that the loading rates had approximately 10% effect on the ASTM test method and no significant effect on the AREMA test method.

- Slowing the load rate to 0.1 in./min for the ASTM test method lowered the MOR and MOE test results by approximately 21% below the 1 in./min test results. Increasing the load rate to 10 in./min for the ASTM test method only increase the 1 and 3% strain stresses and the MOE stresses by 2 to 4% over the 5 in./min load rate. However, increasing the load rate did lower the MOR by approximately 22% and lower the tie deflection at MOR by approximately 47%.

- The stress (load) range used to calculate the flexural MOE has a definite effect on the calculated MOE for all of the tie bending moment tests used for the engineered polymer composite ties. Based on the tests conducted, the stress range of 0 to 600 psi or 1% strain are probably the desirable ranges for engineered polymer composite railroad ties.

- Similar to the MOR test results, the MOE results confirm that the AREMA test method produced approximately 10% higher values than the ASTM test method.

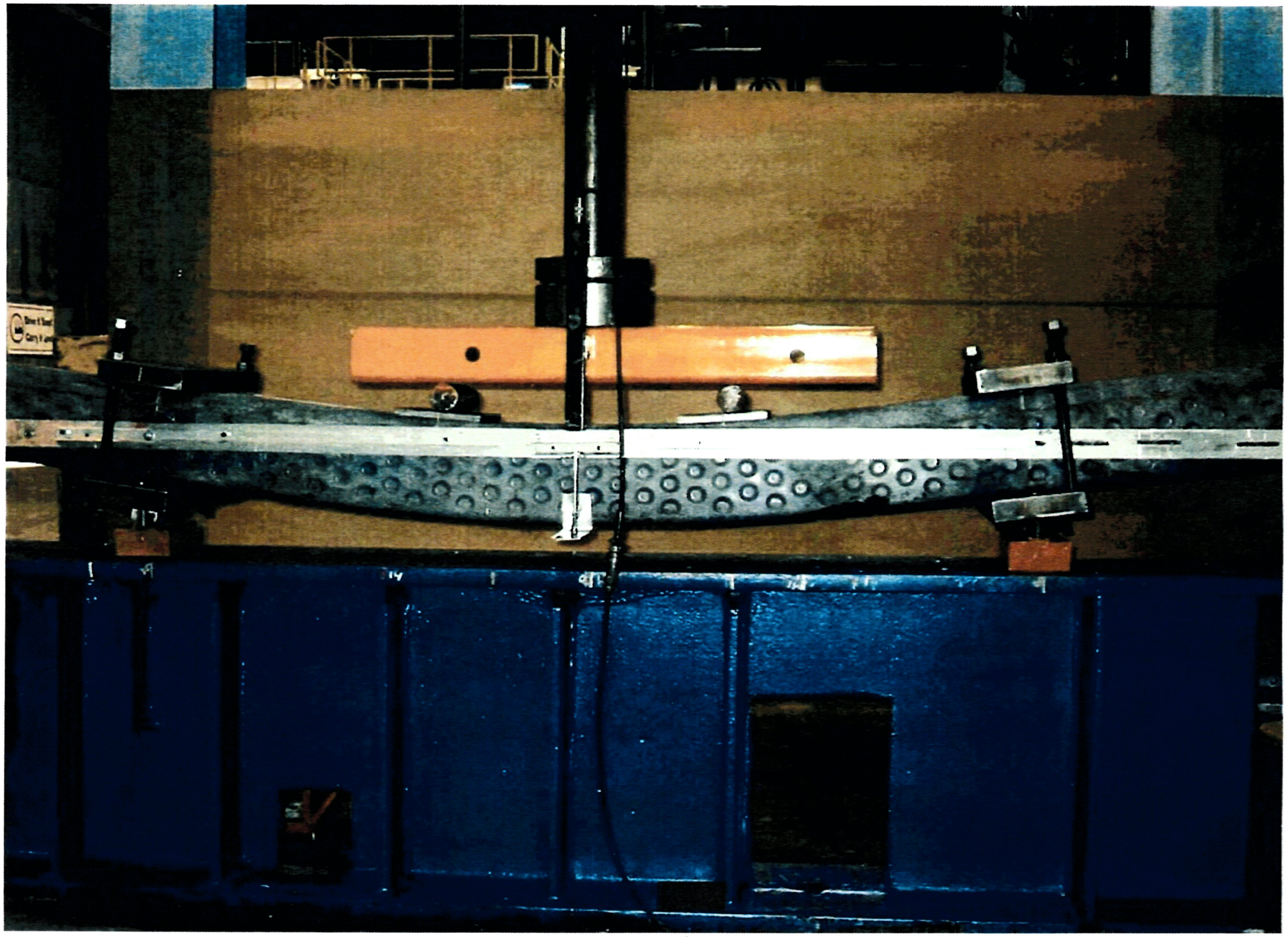

Fig. 4 Test tie under ASTM test loading, prior to modulus of rupture.

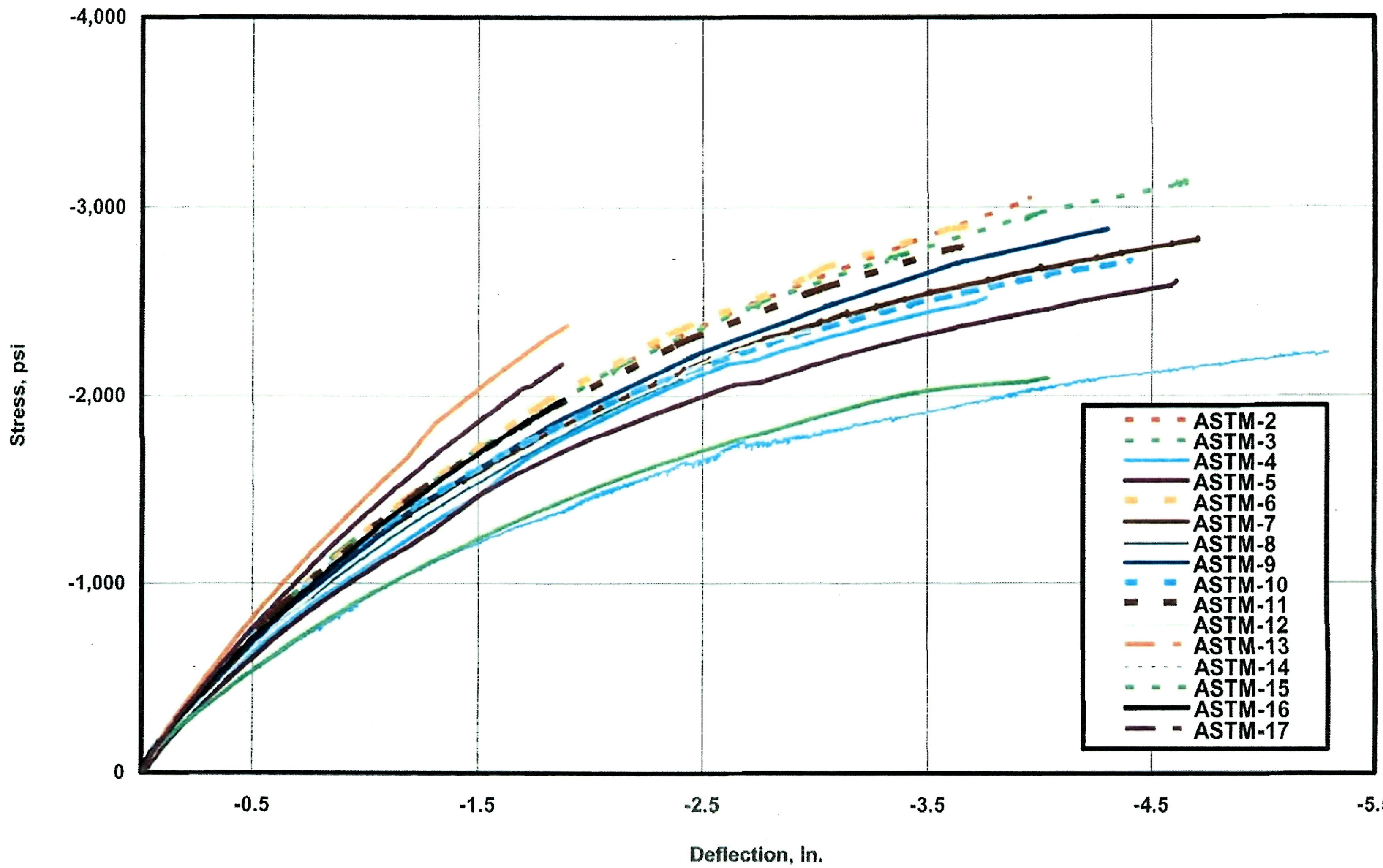

Fig. 5 ASTM test results.

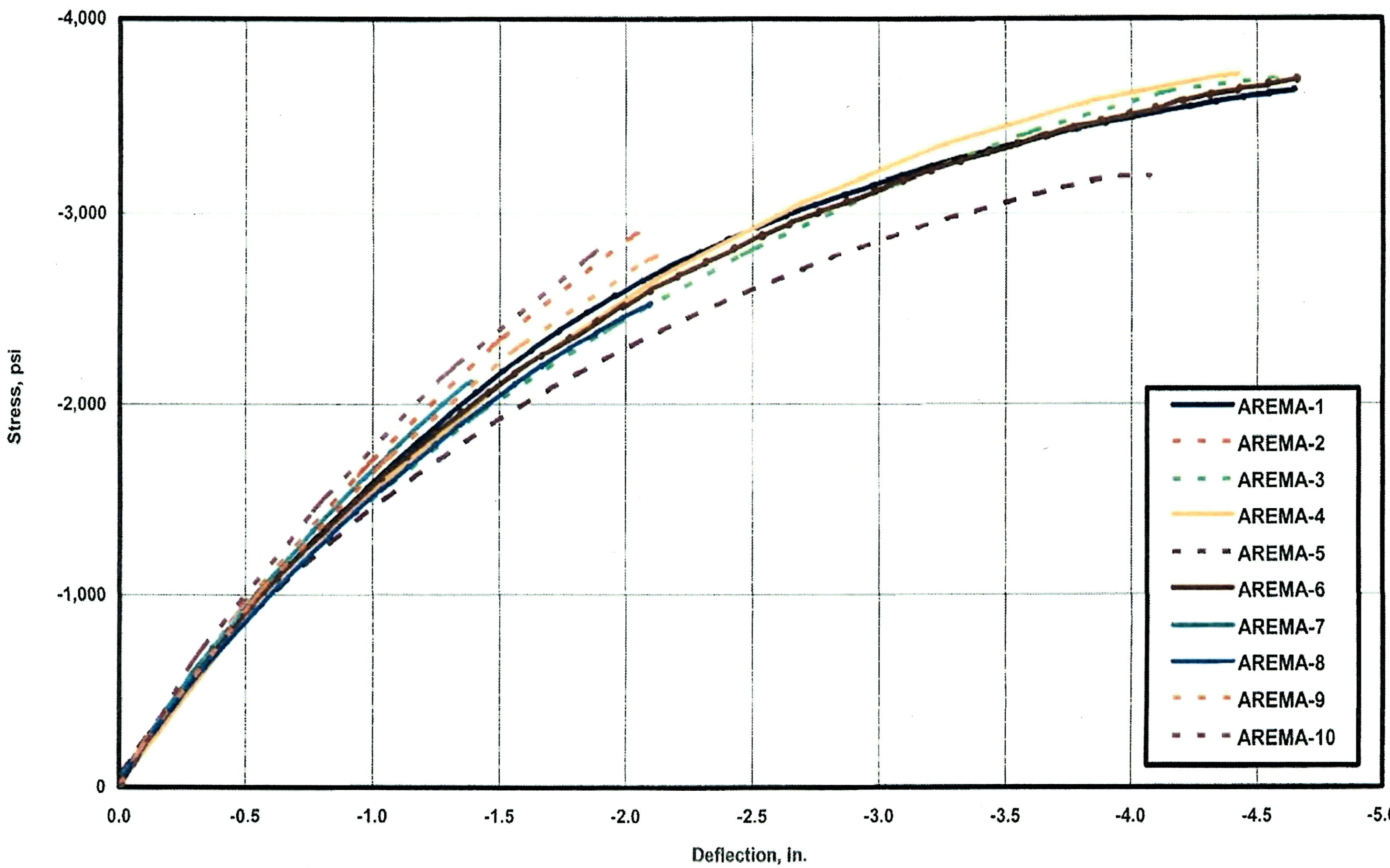

Fig. 6 AREMA test results.

TABLE 2 – TIE BENDING MOMENT TEST STRESSES

Test Method	Loading Rate, in./min.	Tie ID	MOR		Stress, psi	
			Stress, psi	Deflection, in.	1% Strain	3% Strain
ASTM	0.1	ASTM-14	2,212	5.292	959	1,836
	0.1	ASTM-15	2,073	4.042	959	1,950
		Average	**2,143**	**4.667**	**959**	**1,893**
ASTM	1	ASTM-4	2,684	3.758	1,165	2,396
	1	ASTM-5	2,667	4.607	1,133	2,273
	1	ASTM-7	2,823	4.703	1,273	2,473
	1	ASTM-8	2,086	2.406	1,229	Failed
	1	ASTM-9	2,733	4.551	1,376	2,565
		Average	**2,599**	**4.005**	**1,235**	**2,427**
ASTM	5	ASTM-2	2,641	3.954	1,347	2,763
	5	ASTM-3	3,112	4.656	1,369	2,718
	5	ASTM-6	2,899	3.678	1,310	2,756
	5	ASTM-10	2,710	4.551	1,318	2,438
	5	ASTM-11	2,792	3.655	1,350	2,678
		Average	**2,831**	**4.099**	**1,339**	**2,671**
ASTM	10	ASTM-12	2,341	2.974	1,240	-
	10	ASTM-13	2,375	1.901	1,562	-
	10	ASTM-16	1,961	1.880	1,308	-
	10	ASTM-17	2,172	1.877	1,463	-
		Average	**2,212**	**2.158**	**1,393**	**-**
AREMA	1	AREMA-1	3,626	4.652	1,404	2,947
	1	AREMA-4	3,713	4.427	1,342	2,982
	1	AREMA-6	3,679	4.663	1,383	2,900
	1	AREMA-7	2,118	1.386	1,457	Failed
	1	AREMA-8	2,526	2.099	1,343	Failed
		Average	**3,132**	**3.445**	**1,386**	**2,943**
AREMA	5	AREMA-2	2,894	2.052	1,461	Failed
	5	AREMA-3	3,549	4.578	1,342	2,844
	5	AREMA-5	3,181	4.074	1,292	2,628
	5	AREMA-9	2,775	2.129	1,426	Failed
	5	AREMA-10	2,800	1.882	1,559	Failed
		Average	3,040	2.943	1,416	2,736

Notes: For ASTM Tests – 1% strain = 1.09 in. deflection, 3% strain = 3.28 in. deflection
For AREMA Tests – 1% strain = 0.86 in. deflection, 3% strain = 2.56 in. deflection

TABLE 3 – TIE BENDING MOMENT TEST, MODULUS OF ELASTICITY VALUES

Test Method	Loading Rate, in./min.	Tie ID	Modulus of Elasticity (MOE) 0 to 400 psi	0 to 600 psi	1% Strain	3% Strain
ASTM	0.1	ASTM-14	126,000	112,200	92,400	62,000
	0.1	ASTM-15	127,800	114,400	98,900	65,900
		Average	**126,900**	**113,300**	**95,700**	**64,000**
ASTM	1	ASTM-4	147,700	140,000	116,500	79,900
	1	ASTM-5	145,800	137,700	113,300	75,800
	1	ASTM-7	172,700	162,300	127,300	82,400
	1	ASTM-8	163,100	151,100	122,900	Failed
	1	ASTM-9	155,400	146,100	137,600	85,500
		Average	**156,900**	**147,400**	**123,500**	**80,900**
ASTM	5	ASTM-2	173,000	169,600	134,700	92,100
	5	ASTM-3	181,200	177,100	136,900	90,600
	5	ASTM-6	163,700	157,000	131,000	91,900
	5	ASTM-10	177,700	163,900	131,800	81,300
	5	ASTM-11	161,300	154,700	135,000	89,300
		Average	**171,400**	**164,500**	**133,900**	**89,000**
ASTM	10	ASTM-12	150,100	145,200	124,700	Failed
	10	ASTM-13	196,600	185,800	157,100	Failed
	10	ASTM-16	162,300	154,700	140,800	Failed
	10	ASTM-17	180,400	171,200	147,100	Failed
		Average	**172,400**	**164,200**	**142,400**	**-**
AREMA	1	AREMA-1	175,500	171,000	140,400	98,200
	1	AREMA-4	155,500	149,900	134,200	99,400
	1	AREMA-6	167,200	162,100	138,300	96,700
	1	AREMA-7	180,500	171,800	145,700	Failed
	1	AREMA-8	161,600	155,600	134,300	Failed
		Average	**168,100**	**162,100**	**138,600**	**98,100**
AREMA	5	AREMA-2	210,100	180,200	146,100	Failed
	5	AREMA-3	184,600	158,400	134,200	94,800
	5	AREMA-5	186,400	159,900	129,200	87,600
	5	AREMA-9	189,000	162,200	142,600	Failed
	5	AREMA-10	219,200	188,100	155,900	Failed
		Average	**197,900**	**169,800**	**141,600**	**91,200**

APPENDIX A

Stress and Modulus of Elasticity Equations

Flexural Bending Stress Equations

$$\sigma = \frac{Mc}{I}$$

where:

σ – flexural stress, psi
M – bending moment
c – d/2
I – 1/12 (bd^3)
b – tie width (nominal 9")
d – tie width (nominal 7")

For AREMA: $\sigma = 0.204P$

For ASTM: $\sigma = 0.136P$

where:

P – applied load, lb

Flexural Modulus of Elasticity Equations

For AREMA

$$E = \frac{PL^3}{48Iy}$$

E = 17.493 (P/y)

For ASTM

$$E = \frac{23PL^3}{1296Iy}$$

E = 14.904 (P/y)

where:

L – loading span, in. (60)
y – tie center span deflection, in.
P/y – slope of load-deflection curve, lb/in.

Flexural Strain Equations

$$\varepsilon = \sigma/E$$

For AREMA: $\varepsilon = 0.0117y$

For ASTM: $\varepsilon = 0.0091y$

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) has been conducting investigations to help develop and evaluate engineered polymer composite railroad ties since 1993. Recent efforts, through funding and support from the Railway Administration, center around track safety issues relative to the use of these new products in mainline heavy-axle-load track. Performance criteria have been developed and published in Chapter 30 of the American Railway Engineering and Maintenance-of-Way Association's (AREMA) Manual for Railway Engineering. One item not completely resolved in this engineering guidance is the test method procedure to measure the bending strength and modulus of elasticity (stiffness) of the composite ties. The objective of this investigation is to compare variations in bending strength test methods currently being used to measure strength and modulus values for engineered polymer composite railroad ties.

15. SUBJECT TERMS
Polymeric composites–Testing; Polymeric composites–Elastic properties; Bending stresses; Railroad ties; Railroads

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